

## DIGITAL IMAGING METHOD AND APPARATUS FOR MAMMOGRAPHY

The present invention relates generally to imaging of an object by electromagnetic radiation, especially to digital mammography.

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More precisely, the invention relates to a digital imaging method in which the radiation that has passed through the object to be imaged is detected on at least one sensor, which contains one or more preferably elongated sensor modules, wherein the said sensor module contains one or more pixel columns  
10 which receive image data, in which method the object to be imaged is arranged essentially motionless and is scanned across with a beam which originates from a radiation source, the focus of which being essentially motionless in space, the beam being limited to be narrower than the object to be imaged and adapted essentially to the active surface of the sensor, and in which  
15 method the sensor is moved in synch with the scanning movement of the beam while at the same time the said active surface is kept essentially at right angles to the beam on the plane formed by the scanning movement of the beam.

20 The invention also relates to a digital imaging apparatus, which includes a radiation source, a sensor arrangement for detecting radiation, which arrangement contains one or more sensors formed of one or more preferably elongated sensor modules, which sensor module contains one or more pixel columns which receive image data, means for positioning the object to be im-  
25 aged, the said means being situated within the area between the radiation source and the sensor arrangement, means for limiting the beam from the radiation source essentially according to the active sensor surface of the said sensor arrangement, means to move the beam across the object being positioned to be imaged and means to move the said at least one sensor belong-  
30 ing to the sensor arrangement in synch with the said scanning movement of the beam and to keep the said active sensor surface essentially at right angles to the beam on the plane formed by the scanning movement.

In medical x-ray technique digital imaging provides certain advantages compared to the use of film. For example, fewer retakes are needed when a separate photograph developing stage is left out and when a major portion of the "failed" images even may be programmatically adjusted into a form still diagnostically applicable. On the other hand, the radiation dose the patient is exposed to decreases due to the semiconductor sensors being more sensitive than analogous films. While health care and hospital systems move more and more to digital technique in general and thus also to handling the x-ray images and patient information etc. in digital form, there additionally arises new possibilities and advantages related, among other things, to viewing, handling, storing and remote observing of the images having been taken and stored in digital form.

Semiconductor sensors for digital imaging purposes are typically radiation sensitive surfaces formed of small picture elements, or pixels, the extreme case of such surfaces being a line detector with a single line. The electromagnetic radiation, such as light, infra-red or x-ray radiation, which has been absorbed to the area of the pixels forms an electric charge corresponding the quantity and energy of the radiation quanta. So, when the electric charge is formed as a function of time, i.e. when during the 'exposure time' a pixel integrates the electric charge formed within its area, the level of the pixel signal may be adjusted in principle by altering the integration time. However, varying of the integration time does not affect sensitivity of the sensor.

Digital imaging may be implemented as full field imaging where a sensor according to (at least) the dimensions of the object is used, or as scanning imaging where a narrow sensor is used. In view of a practical imaging process, full field imaging corresponds to the traditional imaging onto a film of the size of the whole imaging area. A clear disadvantage of this technology is the need for sensors that are large in area and thus very expensive, and on the other hand the need to take into account the secondary radiation scattering from the object being imaged, which requires e.g. arranging complex mechanical grid structures in front of the detector. Because of their operational principle, the grid structures also even double the radiation dose needed for the imaging.

Narrow sensor is typically used in scanning technique, which requires some mechanics for support. However, such a solution is considerably more economical in total costs than solutions based on a full field sensor, especially due to its smaller sensor area. In scanning imaging also the grid structure may be left out.

Due to the high resolution, i.e. small pixel size needed in mammography, scanning imaging requires in practise use of a sensor of several pixels wide and a so called TDI method (Time Delay Integration) in order to achieve a signal that would be adequate for detecting the radiation by radiation-production of a practical magnitude. Although there are some other possibilities, TDI imaging is usually implemented by CCD sensor technique (Charge Coupled Device).

In US patent publication 5,526,394 there has been presented a prior art digital scanning imaging solution, according to which scanning movement of the beam and the corresponding movement of the sensor arrangement is implemented in a mammography apparatus in mechanical connection with each other with the help of a pendulum in such a way that a collimation element limiting the beam and the sensor arrangement move along a concentric curved path. In the apparatus in question also the compression paddles, which position the tissue to be imaged, have been arranged curved according to the trajectory of the sensor arrangement. The focus of the swinging movement in the apparatus has been arranged to be situated on the level of the focus of the radiation source.

Although it is in principle mechanically simple to keep the sensor arrangement at right angles to the beam according to the solution of the above-mentioned publication, use of it also causes certain problems. For example, as it has been customary in mammography to position and compress the object to be imaged motionless between plane-like compression paddles, the curved compression surfaces are difficult to approve for many people to begin with. Practical problems may also occur, especially when small breasts are being positioned between wide curved surfaces. Additionally, such a way of positioning

the object causes the imaging geometry becoming different compared to the traditional one, which geometry is further affected differently by the thickness of the tissue to be imaged than in the traditional solution. Furthermore, when using curved surfaces, typical special imaging modes used in mammography, such as enlargement, spot and stereotaxic imaging must be implemented in a completely new way, in which case they require specific solutions of their own, and all the traditional imaging modes are not even realizable in connection with such a solution - at least not without completely new special arrangements.

One of the main objects of the present invention is to promote development in digital mammography in such a way that even when scanning imaging is used, from the user's point of view both imaging apparatus and the image to be formed essentially correspond to the traditional film-based full field imaging, i.e. that in case so desired, the invention may be implemented "in a way which is (in principle) invisible to the user of the mammography apparatus". Thus, an additional object of the invention is to enable modifying the existing film-based devices to digital ones with as small changes and costs as possible.

The essential features of the invention are expressed more precisely in the attached claims. These features include that when during the imaging scan the sensor surface is kept continuously at right angles to the beam on a plane formed by its scanning movement, alike according to prior art, the sensor is not moved along a curved path in direction of the scanning movement but essentially along a linear path.

In the following the invention is described more closely with the help of its preferable embodiments and by referring to the following figures, of which figures

Figure 1 presents a typical mammography apparatus,

Figure 2 presents one way of implementing a linear scanning movement of the sensor according to the invention,

Figure 3 presents another possible way of implementing a linear scanning movement of the sensor according to the invention and

Figures 4 and 5 present one sensor module structure well-suited to be used in mammography

10 The mammography apparatus 1 presented in figure 1 consists of a body part 11 and a C-arm 12 connected to it. Typically a radiation source 13 and, e.g. inside the lower shelf 14, image data receiving means 15 are placed on the opposite ends of the C-arm 12, which imaging means 13, 15 when being situated inside the cover of the apparatus are not actually visible in figure 1. Additionally, means 16, 17 for positioning the object to be imaged within the imaging area are located within the area between these imaging means 13, 15, typically near the image data receiving means 15. Typically, the C-arm 12 is movable both in vertical direction in relation to means 16, 17 for positioning the object to be imaged and rotatable in relation to the body part 11. The positioning means 16, 17 are typically formed of an upper compression paddle 16 and a lower compression paddle 17, which lower compression paddle 17 may be arranged to function as a so called bucky as well. Bucky means a grid structure located between the tissue to be imaged and the image data receiving means, which grid structure restricts access of the radiation scattered from the tissue to the image data receiving means.

In figure 2, which is not drawn in scale, is presented in a simplified manner one way to implement a sensor arrangement 15 of a mammography apparatus according to the invention. In the upper part of figure 2 there is presented a radiation source 13 and its focus 42, the radiation source being situated at the first end of the C-arm 12. Between the radiation source 13 and the object to be imaged there is a collimator apparatus including a collimator 19, which is arranged to be moved in synch with at least one sensor 50 belonging to the sensor arrangement 15 of the imaging apparatus. The collimator apparatus

consists of an actuator 20, such as a motor, which may be operated programmatically and makes a bearing-mounted 22 screw 21 rotate. In the collimator 19 there are ledges 23 or equivalent, which include such an inner thread fitted to the screw 21 that when the screw 21 is rotated, the collimator  
5 19 moves in direction of the middle axis of the screw 21. In figure 2 the arrow 33 presents the direction of the scanning movement of the beam defined by the collimator 19.

In the solution according to figure 2, the radiolucent upper and lower compression paddles 16, 17 function as positioning means of the object to be imaged, which compression paddles are located between the radiation source 13 and the lower shelf 14, which is situated at the other end of the C-arm in such a way that the lower shelf 14 is situated near the lower surface of the lower compression paddle 17. The lower shelf 14 as such can be arranged to  
15 function also as the lower compression paddle 17. The surfaces of the compression paddles 16, 17, which become against the object to be imaged, are essentially plane-like.

The sensor arrangement 15, which is situated in the essential vicinity of the  
20 lower compression paddle 17 inside the lower shelf 14, is implemented according to figure 2 by connecting the image data receiving sensor 50 to a transmission element 28, which is equipped with an inner thread and through which extends a rotatable bearing-mounted 26 screw 25, said screw being preferably programmatically operable by an actuator 24, such as a motor.  
25 When the screw 25 rotates, the sensor 50 moves in a linear fashion in the direction of the middle axis of the screw 25. Additionally, a bearing-mounted or an articulated connection has been arranged between the transmission element 28 and the sensor 50 to enable their mutual rotational movement. Further, a longitudinal control arm 30 is attached motionless to the sensor 50,  
30 which control arm is essentially straight and extends away from the sensor 50 in direction of the beam. Further, in the control arm 30 there is a longitudinal trajectory groove 31 extending essentially in the direction of the beam, in which groove there is fitted a control element 29, respectively, which can thus move in the direction of the longitudinal axis of the control arm 30. The control

element 29 according to figure 2 consists of a body, which has three projections extending outwards from the centre of the body, the projections being at 120° angles to each other and having rollers 32 at their ends. The rollers 32 are pivoted to be rotatable around their middle axles. Within the lower shelf 14 there is further arranged a longitudinal curved guide groove 34, the radius of curvature of which corresponds the distance of the groove 34 from the focus 42 of the radiation source 13. The control element 29 is arranged movable in the guide groove 34.

10 In practise, the solution according to figure 2 functions such that when the sensor 50 is moved essentially linearly along the screw 21 by control of the actuator 24, whereby it concurrently moves the control element 29 along the curved guide groove 34, position of the sensor 50 in relation to the direction of the linear movement determined by the screw 21 continuously tilts in such a way that the active surface of the sensor 50 remains essentially at right angles to the beam on the plane formed by the scanning movement of the beam, because of being guided by the shape of the guide groove 34 as well as the structures arranged for the control arm 31 and the transmission element 28. During the imaging scan the control arrangement of the imaging apparatus 1 controls the actuators 20, 24 which rotate the screws 21 and 25 in such a way that during the imaging scan the beam originating from the radiation source 13 and being defined by the collimator 19 moves in synch with the active surface of the sensor 50, i.e. in a way that the collimator 19 and the sensor 50 move in the same direction with speeds synchronized with each other.

25 The linear movement of the collimator 19 and the sensor 50 can be arranged synchronized also by connecting them together mechanically. Likewise, means may be arranged to the collimator 19 for adjusting the width of the beam during the imaging scan.

30 In figure 3, which is not drawn in scale either, is presented in a simplified manner another way of implementing the sensor arrangement 15 of the mammography apparatus 1 according to the invention. In this solution, a pendulum arm 35 is arranged to the imaging apparatus, the focus of rotation of which being

- arranged on the level of the focus 42 of the radiation source 13. Moving of the collimator 19 (not shown in figure 3), which is arranged in close proximity to the radiation source 13, may be implemented not only as according to figure 2 but also by arranging it in mechanical connection with the pendulum arm 35 in such a way that the collimator 19 follows the movements of the pendulum arm 35. Such a structure additionally includes an actuator (not shown in the figure) for producing the movement 41 of the pendulum arm 35 with respect to the focus of rotation 42.
- 10 In the solution according to figure 3, the sensor 50 receiving image information is attached motionless to the lower part of the pendulum arm 35 with the exception that it is allowed to move in the direction of the longitudinal axis of the pendulum arm 35, e.g. along a guide groove 39 arranged to the pendulum arm 35. Additionally, a transmission element 40 is connected to the sensor 50, 15 which element is connected by a bearing-mounted or an articulated connection to a control element 37 equipped with wheels 38 to enable mutual rotational movement between the sensor 50 and the control element 37. This makes possible moving the sensor 50 along a linear guide groove 36 arranged inside the lower shelf 14 with the help of the pendulum arm 35 in such a way that because of the control provided by the structures arranged for the 20 transmission element 40 and the control element 37, i.e. when moving in relation to the pendulum arm 35 only in the direction of the beam, the sensor remains continuously essentially at right angles to the beam on a plane formed by its scanning movement. If movement of the radiation source 13, and/or that of the collimator 19 being arranged in close proximity to it, is mechanically 25 connected to the movement of the pendulum arm 35, too, the scanning movement of the beam and the sensor 50 can be synchronized by a mechanically forced control.
- 30 The solution according to figure 3 can be modified e.g. such that the sensor 50 is attached to the pendulum arm 35 completely motionless and the pendulum arm 35 will be provided with means, such as a telescope structure, for altering its length in such a way that the movement of the sensor 50 in the scanning direction becomes linear. This makes it possible to implement the

lower shelf 14 of the imaging apparatus 1 in a manner which is relatively simple and even less bulky.

It is self-evident to a person skilled in the art that moving of the sensor can be implemented by other means than those presented above, too, e.g. by arranging a separate actuator to tilt the sensor or by moving the sensor and/or a guide element attached motionlessly to it in a guide groove or a tunnel, which is designed such that also the sensor movement according to the invention will be accomplished by a mechanically forced control. Likewise, the possible linear movement of the collimator may be implemented by a corresponding manner self-evident to a person skilled in the art as the linear movement of the sensor. More generally speaking, when considering the structure of an existing film based mammography apparatuses, perhaps solutions most corresponding to their outer dimensions and where minimum changes are required can be reached by arranging both the linear and tilting movement of the sensor to be implemented with separate actuators. Naturally, separate actuators may also be arranged for realizing all the movements needed for accomplishing the scanning movement of the beam.

In figure 4 there is presented one practical sensor module solution to form a TDI sensor suitable for use in scanning imaging. The sensor 50 can consist of e.g. four in the scanning direction consecutive sensor module columns 51, 52, 53, 54, in which columns separate sensor modules 510, 510', ... are placed at right angles to the scanning movement 33 in slightly different positions such that the possible seams of the sensor surfaces of the modules 510, 510', ... will become placed at slightly various heights in each column. This secures that the possible gaps between the modules 510, 510', ... will be imaged anyhow via the three other module columns and no gaps will be left in the image formed. The overlap may be implemented by e.g. as a multiple of the pixel size of the sensor module added with a quotient, which depends on the number of modules involved in the image formation and the pixel size according to a calculation formula  $dpix \times (n+1/m)$ , where  $dpix$  = diameter of the pixel,  $n$  = integer and  $m$  = number of the modules in the observation direction or an integer smaller than that, whereby the imaging resolution of the sensor module

may be increased to be higher than that of the physical pixel size with the help of signal processing functions.

The corresponding overlaps and distances between the modules 510, 510', ...  
 5 may also be implemented between those sensor modules consecutive in the scanning direction, whereupon also the resolution in the direction of the scanning movement may be increased correspondingly. On the other hand, separate sensor modules 510, 510', ... may be clocked in a way self-evident to a person skilled in the art to achieve a corresponding effect that increases resolution also in the direction of the scanning movement.  
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In mammography applications a single module 510, 510', ... may be formed of e.g. 142 x 284 pixels of 35  $\mu$ m and may form a sensor surface of an area of 5 mm x 10 mm, when the sensor arrangement as a whole may contain e.g. in  
 15 the width direction four and in the height direction about 20 such modules, thereby forming a sensor 50 of ca. 20 mm by width and e.g. ca. 240 mm by height.

It is recommended to keep the gaps between the sensor modules 510, 510',  
 20 ... as small as possible not only in view of the physical dimensions of the sensor arrangement 15 as a whole but also in order to keep the imaging time needed for implementing the scanning movement as short as possible, so that unnecessary problems would not be created due to a possible uneven production of radiation in the radiation source or as a consequence of the object  
 25 to be imaged moving during the imaging scan. In view of forming a seamless image the distance between the modules 510, 510', ... is not critical. For example, a shift register may be arranged on the other of the vertical edges of each sensor module 510, 510', ... without the space occupied by it essentially troubling the imaging.

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In figure 5 it has been clarified how in the module column formed of two or more sensor modules 510, 510', ... each of the modules may be placed essentially at right angles to the focus 42 of the beam used in the imaging also in the direction perpendicular to the scanning direction.

The invention is described above only with the help of a few possible embodiments. It is self-evident to a man skilled in the art that the basic idea of the invention may be implemented in several different ways and its various embodiments are not limited to the examples described above but they may

5 vary within the scope of protection defined in the following patent claims.